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Experiments with short electric waves. 1930.

# EXPERIMENTS WITH SHORT ELECTRIC WAVES

## (5 meters and lower)

PART A

The effect of different conditions on short wave electromagnetic radiations.

PART B

The generation of waves shorter than five meters.

By

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An investigation carried out under the direction of Dr. H.J. Macleod.

Presented to the Committee on Graduate Studies, The University of Alberta, as a partial requirement for the Degree of Master of Science.

University of Alberta,
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## SUMMARY OF INVESTIGATION

This research has been divided into two parts, A and B.

Part A consists of an investigation into certain peculiar diurnal variations which were observed by a previous experimenter in the radiation from a five-meter radio osciallator. A repetition of his experiments, and their subsequent analysis showed that his results might be explained by variations in the input and in the surrounding temperature.

These factors were then investigated, and found to be of importance with certain vacuum tubes, while with others their effect on the radiation was negligible, providing the tubes were operated at rated filament current in all cases. An explanation is given.

Certain peculiarities in wave-length measurements on Lecher-wires are recorded, and the best method for making these measurements is pointed out.

Part B is an account of attempts that were made with certain vacuum tubes to produce wave-lengths below five meters. By ordinary methods, using several different circuits, the low limit for strong oscillations was found to be about 1.61 meters.

It was then discovered that by using a combination of A.C. and D.C. for the plate supply, stronger and more stable oscillations were produced than with pure D.C. It was found possible to produce shorter wave-lengths with this combination than with D.C. alone.

PART A : The Effect of Different Conditions on Short Wave Electromagnetic Radiations.

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## INTRODUCTION

The subject of electromagnetic wave propagation has been responsible for a great many investigations, and a number of theories have been suggested to explain the various phenomena involved. Based upon the explanations put forward by Kennelly and Heaviside, who postulated an ionized layer of gas in the upper atmosphere, theories of reflection were developed and contributions made by many physicists and engineers. More recently a refraction theory has been suggested by Hoyt Taylor and Hulburt [1] and by means of this theory the peculiarities of short-wave and long-wave radio transmission have received a satisfactory explanation.

Although the behaviour of electromagnetic waves after they leave the oscillator has received such a great deal of attention, very little experimental evidence has been forthcoming as to the effect on the oscillator itself of varying intensities of

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(1) Phys. Rev. Vol. 27, 1926, p. 189.
QST, October, 1925, p.12.

of light, changing conditions of temperature and humidity, etc. At first thought one might not expect these quantities to have any effect at all, or at least not a measurable one. However, one or two experiments which have been performed in the past would seem to indicate that such effects may occur and may in some cases be quite considerable.

Guyer and Austin (2) record some experiments which were carried out at 5 meters, and state that temperature and humidity, varying from day to day, affected the frequency of the oscillator to some considerable extent. To quote from their report: "The frequency variation by temperature and humidity was proved by placing one of the transmitters under a glass jar and introducing a small amount of sulphuric acid...". It is to be noted that they did not observe (or at least, did not mention) any variation in radiated energy, the effect being a shift in frequency only.

C.H. West (3), working on a wave-length of 5.17 meters, claims to have observed a considerable change in radiated energy with variations in the intensity of light falling on the transmitter. The radiation

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(2) QST, July, 1927, p.29.
(3) Radio Engineering, June, 1929, p.53

The radiation was at a maximum in the middle of the day, fell off in the afternoon, and became a minimum when darkness fell (the assumption is that the input was maintained constant during the course of the experiment). He found also that the daylight radiation value could be obtained at night by artificially illuminating the oscillator; so that artificial light and sunlight were equally effective in producing a noticeable change in the radiated energy.

The frequency shift with variations in the temperature and humidity, noticed by Guyer and Austin, might be accounted for by,

(a) temperature and humidity changes affecting the dielectric constant of the condenser (air being the dielectric), and

(b) temperature changes conceivably affecting the diameter of the heavy copper wire (used for coils and wiring) sufficiently to cause a noticeable frequency change.

The phenomenon observed by West is, however, not so easily explained; in fact, that visible light can in any way affect the generation of electromagnetic waves of such a different frequency is almost inconceivable. Imagine for a moment, however, that some

part of the transmitter is absorbing energy from the incident light and emitting it at the wavelength at which the oscillator is working (in West's case, 5.17 meters). This would explain West's observations, and would be classified as a fluorescent effect. In fluorescence, a molecule (or single atom) absorbs light at one frequency and emits it at the same or some other frequency. In this case we might imagine the re-emission to be occurring at a lower frequency. For this absorption and re-radiation to take place, the absorbing molecule must have a characteristic frequency corresponding to the absorbed light and a characteristic frequency corresponding to that of the re-radiation. But even the molecular rotation and vibration spectra do not give wavelengths longer than the long infra-red --- certainly none in the vicinity of 5 meters --- and therefore molecular absorption and re-radiation cannot be used to explain West's results. So that, on modern theories of physics, the results which West claimed to have obtained are quite inexplicable.

Hence it was decided to repeat the experiments that C.H. West had conducted, and determine if his variations in radiation were not really due to some

other disturbing factor, the effect of which might or might not have been isolated before.

THE OSCILLATOR

Since the effects mentioned above were all noticed with the transmitters working at about five meters, and since there was a possibility that frequency might have something to do with the results obtained, it was decided to build a transmitter to operate at about that wave-length.

An examination of the literature revealed the fact that the circuit [4] shown in Figure 1 is one of the most stable and easily adjusted at ultra-high frequencies, and an oscillator using this circuit was accordingly constructed.

Referring to the diagram, C is a variable, 500 mmfd. condenser, with a minimum value of probably about 15 mmfd. R.F.C.$_{1,2,3,4}$ are radio-frequency chokes, made up of 20 turns of #26 wire wound on one-inch celluloid forms. $L_1$ and $L_2$ are two pieces of copper tubing, 0.6 cm. x 86 cm. The vacuum tube is a five-watt, Northern Electric 205D. The value of the

(4) Phil. Mag., 1921, V.42, P.266, Townsend and Morrell.
Phil. Mag., 1922, V44, P.164, Gill and Morrell.
Phil. Mag., 1926, V. 2, P.130, Gill and Donaldson.
QST, 1929, July, P.30, W.J. Lee.

Figure 1

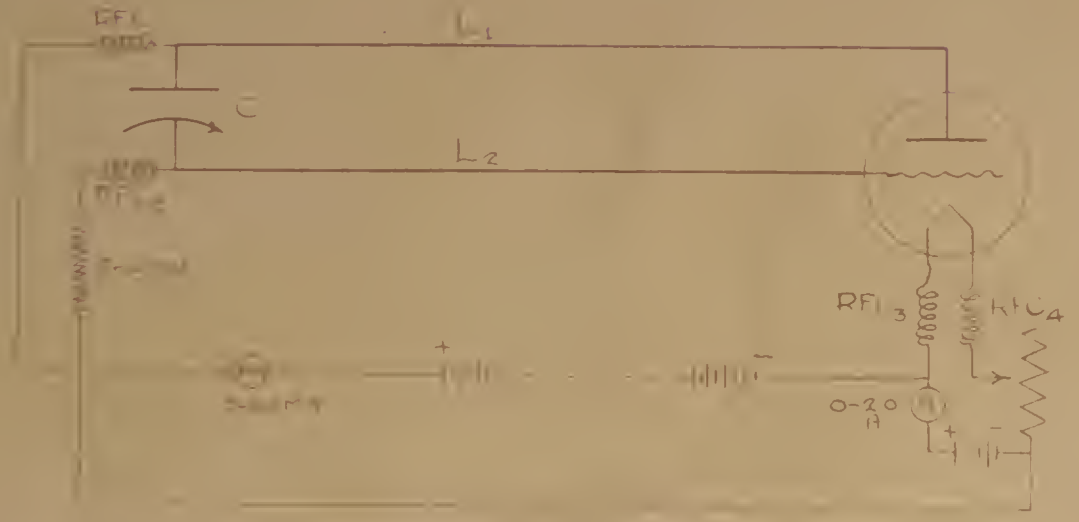



Figure 2

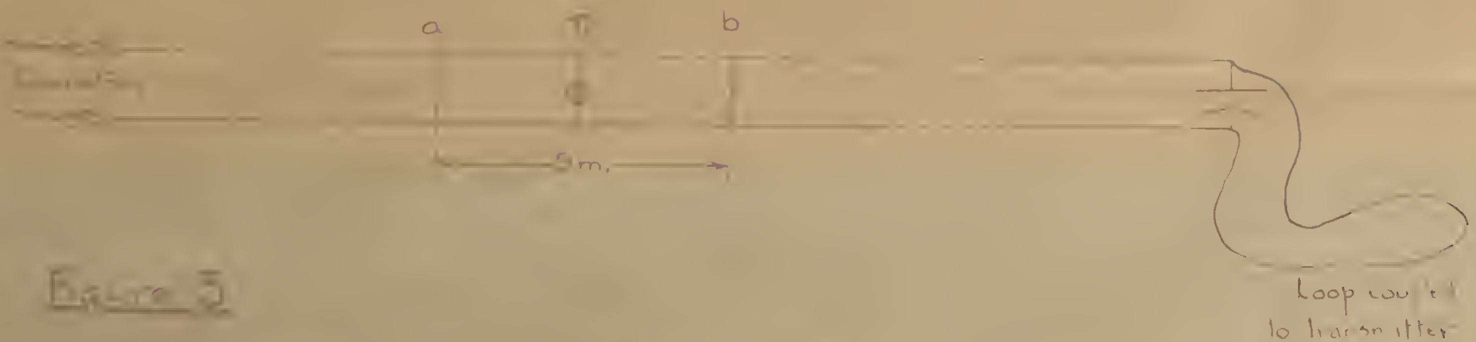
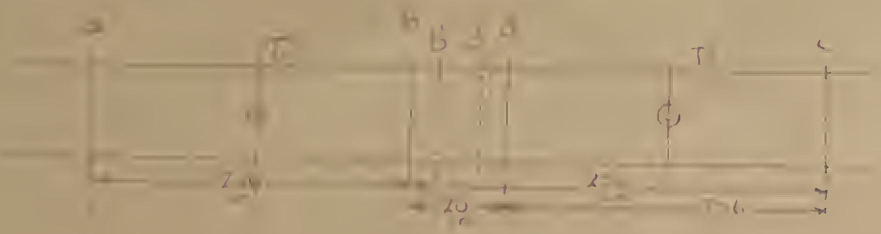



Figure 3



gridleak is 10,000 ohms.

The transmitter, when constructed, was found to oscillate very freely over the entire condenser scale.

MEASURING THE WAVE-LENGTH

To measure the wave-length of the generated waves, a Lecher-wire system [5] was set up (see Fig. 2), and several methods of procedure were adopted. The condenser was inserted to tune the system to resonance, the resonance point being indicated by a kick of the plate milliammeter.

Method 1.

A neon glow-lamp, made by the General Electric Company, was suspended from the two wires and moved along them until a potential anti-node was reached. The tube then glowed brightly. A piece of wire, forming a short-circuiting bridge, was moved to various positions on the wires. When at the point (a), the tube glowed brightly as before. This indicated that (a) was a potential node. Moving the wire a centimeter or less from position (a) caused the tube to go out. A second wire was laid at (b)

(5) Principles of Electric Wave Teleg. and Telephony, J.A. Fleming, P.320.
Electricity and Magnetism, S.G.Starling, P.458
QST. Oct., 1924, R.S.Kruse, P.13.

and adjusted so that the tube still glowed brightly. (b) was then also a potential node. Since the anti-node, as determined by the glowing tube, was nearly mid-way between (a) and (b) --- two nodes --- it was a sumed that the distance (a) to (b) was half a wave-length. This distance was about five meters, so the complete wave-length was taken as 2 x 5 = 10 meters.

This value for $\lambda$ did not seem quite right, as the lengths of rods used, by comparison with the results of previous investigators (6), would indicate a wave-length of only about half that or five meters. For instance, consider the oscillator employed by Gill and Donaldson. They were using rods 161 cm. long, which gave them a wave-length of 8.25 meters; and they estimated that a reduction of X in the length of the rods would reduce the wave-length by about 4X. This was found by them to be roughly true experimentally. In our case, the rods were 86 cm. long; that is, X = 75 cm. The expected reduction in wave-length would then be 4X = 4 x 75 cm. = 3.00 meters. In other words, our transmitter might be expected to radiate on about 8.25 - 3.00 = 5.25 meters.

Some variation from the calculated wave-length (5.25 m.) is to be expected, on account of the

(6) See Note (4)

different grid-to-plate capacities of the tubes used; but this factor would hardly change the wave-length by 100%.

It therefore seemed probable that there was something wrong with the Lecher-wire measurements, and they were accordingly repeated.

The tube ($T_1$) was placed at an antinode, and point (a) found as before. This time (a) was only some 100 cms. from $T_1$, whereas previously it had been nearly 250 cms. from the tube. The second point (b) was found at a distance of 206 cms. from (a).

It was decided to use a second neon tube ($T_2$), which was available, and block off another half wave-length. So $T_2$ was placed as shown, and a third shorting bridge adjusted at a point (c) (Fig. 3). It was then found that whereas distance a-b was about 206 cms., distance b-c was about 226 cms., both distances representing presumably half a wave-length.

A fourth piece of wire was placed across the two Lecher wires, and when adjusted to the position (d), both tubes still glowed steadily. At this stage, therefore, there were shorting wires at a,b,c,d (presumably nodes), and neon tubes at $T_1$ and $T_2$ (assumed to be antinodes).

An attempt was then made to bring the wires at (b) and (d) together. It was found that the distance b-d could be decreased from its original value of about 20 cm. to zero, though moving the wires from (b) and (d) made the glow-tubes very unstable. That is to say, if the wires were in some other position (say b' and d'), the voltage at $T_1$ and $T_2$ apparently dropped very nearly to the critical voltage of the tube. By "critical voltage" is meant the minimum value which will cause a discharge through the tube.

An investigation into the voltage distribution along the wires was next attempted. Positions (a) and (b) for the shorting wires (tube $T_1$ as before) were found by adjustment. The second tube, and wires (c) and (d) were left off. The glow-tube was then moved along the wires, first towards (a) and then towards (b). By estimating the voltage from the brightness of glow of the tube, the shape of the voltage curve along the wire was plotted (fig. 4). An examination of this curve and of the ones in the succeeding figures will show that while none of these curves are pure sine waves, they are of a complex type such as would be formed by a number of the odd harmonics (3rd., 5th., 7th., etc.)

Figure 4

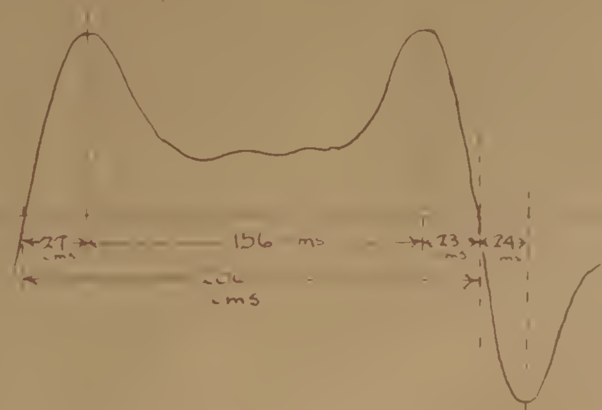



Figure 4a

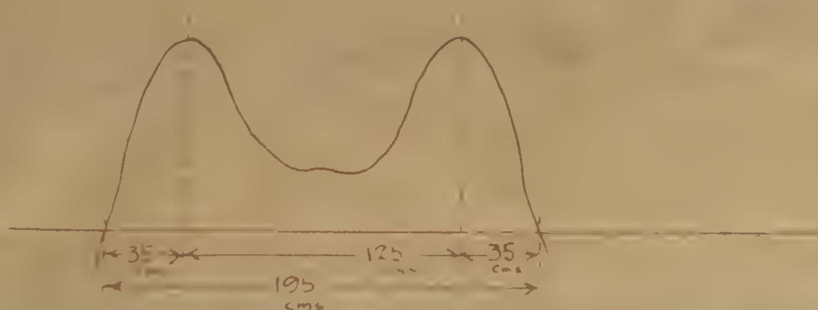
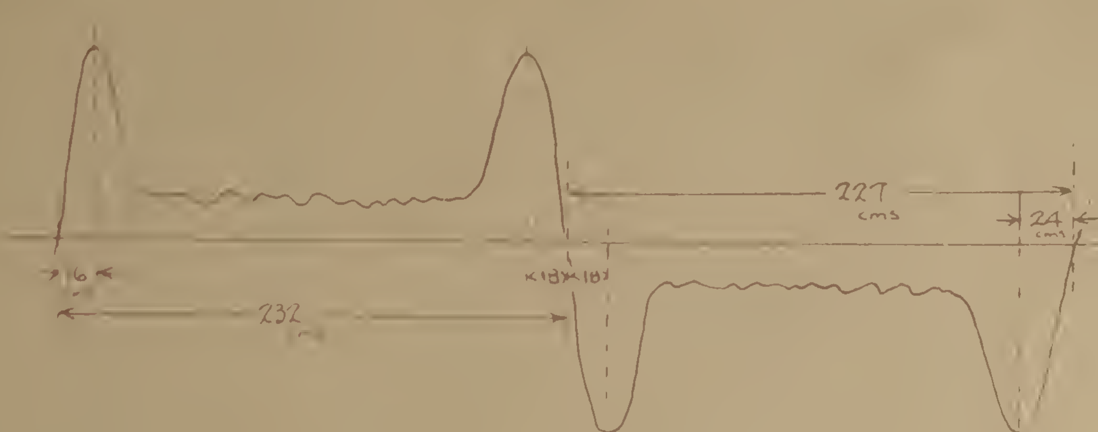



Figure 5



impressed on a fundamental sine wave. Whether these harmonics were actually present or not is not definitely assured, because of the presence of other peculiarities in the Lecher-wire system (see next paragraph).

Using two tubes and three shorting bridges, the bridges were placed at nodes, and the antinodes were examined with the neon tubes. A curve such as Figure 5 resulted. Note that using the two tubes and three shorting wires gives a different distance from node to node than was obtained with one tube and two bridges. It was also noticed that if the nodes were found at some other part of the Lecher-wire system (which was about ten meters long), the distance from node to node was different. Compare figures 4, 4a, 5, which were obtained at different places on the wires.

These results led to the belief that the neon tubes and shorting bridges might form resonance circuits superimposed on the fundamental Lecher wire circuit of such a character that the nodes varied with the part of the Lecher system upon which the extra circuit was imposed.

That these glow-tubes really had some effect on the system was proven by noting the effect that one

glow-tube had on the other. With both tubes off maximum voltage points far enough so that they were glowing unstably, occasionally one would go out. It was started again by discharging on to it a small electrostatic charge (the operator would slide on the floor and accumulate a charge, and then discharge it on the tube by touching the glass with his finger). As soon as the tube burst into a glow, the second tube would in many cases go out. By starting the second tube as the first one had been started, the latter would likewise go out. That is, the tubes had a reciprocative action.

It was thought that the tubes might be working as condensers, though of course the capacity would be very small. The electrodes in the tubes are semi-cylinders, with a fairly large area; so to reduce any capacitance effect, only one of these electrodes was used, and for the other electrode a piece of wire was tied with string to the outside of the bulb, just touching it at the top. Any condenser effect was thus reduced to a negligible quantity. There was no perceptible improvement in the standing wave system. Hence any effect that the tubes have on the oscillations must be due to their conducting properties.

Method 2

For this method, one of the glow-tubes was connected at the end of the wires. Assuming that the neon tube did affect the standing waves on the wires, by placing it on the end a constant end effect was introduced, which did not affect the waves on the rest of the wires.

Using the shorting bridges as before, points were found (nodes) where the presence of these bridges did not cause the tube to cease glowing. By this method it was found possible to place the bridges accurately to within one or two centimeters. A sample of the readings obtained is as follows,-

Dist. between 1st. and 2nd. nodes $(=\frac{\lambda}{2})$ = 254 cms.

" " 2nd. " 3rd. " $(=\frac{\lambda}{2})$ = 252 "

$\lambda \doteq 506$ "

It will be noticed that this wave-length is considerably greater than would be indicated by the results of Method 1, and is a further indication of the disturbing effect of the glow-tubes when placed between the shorting bridges.

Method 3

It was thought that greater accuracy might be obtained by replacing the glow-tube by a thermo-galvanometer. Accordingly, a galvanometer was don-

nected across the far end of the wires. In tuning the circuit now, the procedure was to adjust the condenser until a maximum current flowed through the galvanometer. There was then at this point a current loop, corresponding to a voltage node. This represented resonance for the circuit, just as in Method 2, where the voltage antinode at the end of the wires was indicated by the tube glowing.

In this case, adjusting a shorting bridge to a nodal point caused an abrupt rise in galvanometer current. This rise was so sudden that the bridge was easily placed to an accuracy of a millimeter. A piece of light string was knotted to one of the wires at the nodal point, and a second node was found with the bridge as before. Four of these points were found, and the half-wave lengths, as measured on the wire, all agreed to a small fraction of a centimeter. No attempt was made to record wave-lengths to an accuracy greater than one centimeter, as such was not required; but it would seem quite easy to obtain wave-lengths to a millimeter, accurately.

To determine the effect of the blocking condenser (C, Fig. 1) on the wave-length, a number of measurements were made on the Lecher wires, and a curve was plotted of wave-lengths against condenser readings (Fig. 6). The shortest wave-length obtainable was 5.01 meters, and the longest about 6.5 meters. To obtain longer waves, the rods would have to be lengthened; and for shorter waves, the reverse is true. In the transmitter as constructed, the condenser was connected to the end of the rods, but if there had been a need for greater variation in wave-length than was obtainable merely with the condenser, it could have been obtained by having the condenser attached to sliding clips on the rods, as the wave-lengths of the oscillations are fixed by the lengths of the rods, the capacity of the tube and the capacity of the blocking condenser. If that had been done, however, it should be mentioned that the overhanging rods would have formed a coupled circuit, which would have affected the frequency of the oscillations whenever it approached resonance with the oscillating circuit.

The importance of the length of the rods in fixing the wave-length will be realised when we again mention the fact (4) that a change of X in this length

Figure 6

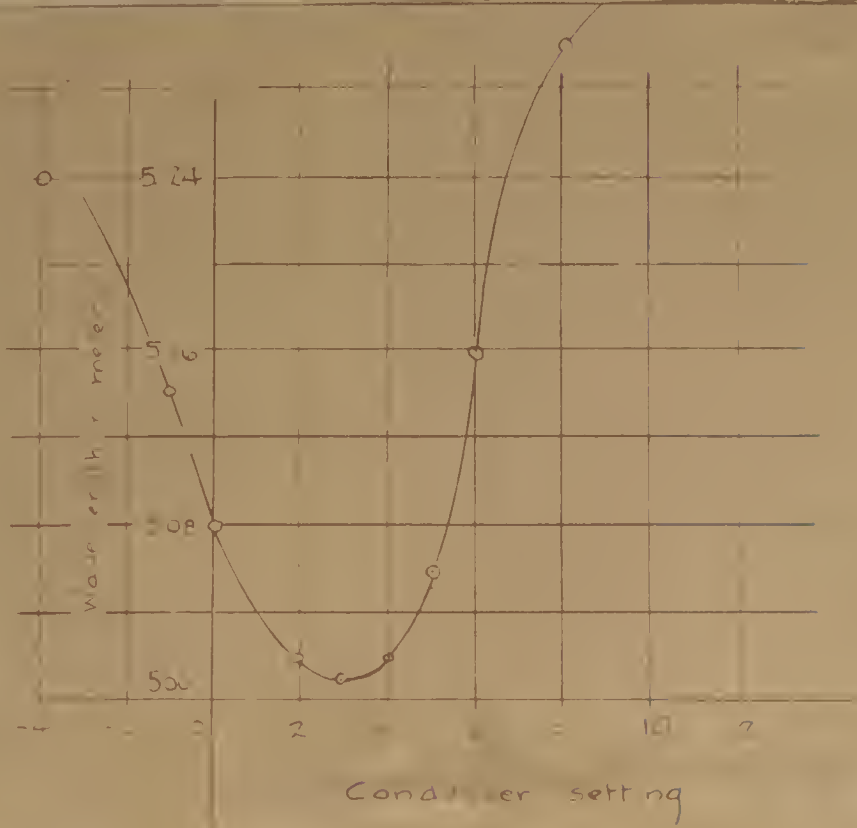
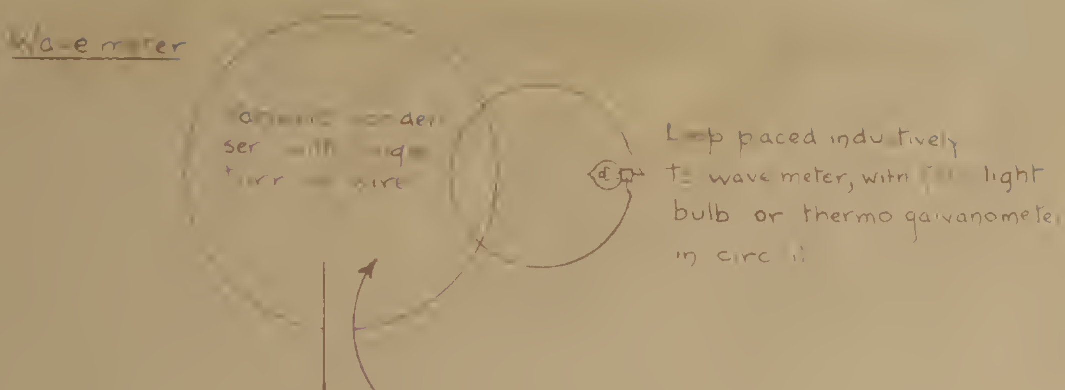



Figure 7



changes the wave-length by 4X.

Wave-meter method

Just after the above measurements had been taken, a General Radio Company wave-meter was procured. This wave-meter is constructed as shown in Fig. 7, consisting simply of an inductance and capacity in series. The range of the meter is approximately 4.5 to 6 meters.

As no indicator accompanies this instrument, a neon tube was connected across the condenser plates to indicate resonance. The oscillator was set going, and the wave-length measured with the Lecher wires. The result of this measurement was 5.02 meters. The wave-meter was then adjusted until the neon tube glowed most brightly. A glance at the calibration chart showed the condenser setting to correspond to a wave-length of 4.5 meters --- quite a difference. This is another indication of the effect of the glow-tube on an oscillating circuit.

Another method was then adopted. A single turn of wire was connected to a thermo-galvanometer and placed in inductive relation to the single loop on the wave-meter. Resonance was indicated by a very abrupt rise in the galvanometer reading. When the wire was not placed too close to the wave-meter coil, no perceptible

disturbing effect on the wave-meter circuit was observed; that is, the resonant frequency of the wave-meter remained for any condenser setting as indicated by the wave-meter chart, and was not changed to some other value by the proximity of the wire. This was checked by reading the wave-length at two points (5.02 and 5.32 meters), first with the Lecher wires and then with the wave-meter. The agreement was perfect.

ANTENNA OR RADIATING SYSTEM

Replacing the Lecher wires, which had been loosely coupled to the rods $L_1$ and $L_2$ two brass rods, 56 cm. long, were coupled to $L_1$ and $L_2$ by means of a wire loop, and fixed upright a foot or so away from the transmitter. They formed an aerial and counterpoise system.

The oscillator was set going, and allowed to come to equilibrium. To measure and detect any radiation changes, the wavemeter and thermo-galvanometer were placed near enough to the aerial system to get a fairly large reading on the galvanometer, so that changes would be more easily observed. Using the wavemeter in this way, a good idea is obtained of any change in radiated energy, as well as any frequency variation.

A few experiments were carried out with the antenna and counterpoise rods. For instance, it was

found that varying the distance between the tops of the rods (they were pivoted at the bottom) affected the frequency of the oscillator to some extent. Also, placing the rods side by side is not a very efficient method of obtaining good radiation. This is to be expected, because the magnetic and electric fields starting from the two rods tend to become cancelled (the field from one rod by the field from the other). If the rods ~~were~~ are at right angles, the radiation is increased about tenfold, and remains approximately the same when they are placed in line.

A long brass cylinder happened to be nearby, and this was placed over one of the rods to see how the radiation would be affected. With the cylinder touching the rod, the radiation was considerably reduced. With the cylinder and rod insulated by means of two thicknesses of paper, the radiation was the same with and without the cylinder on the rod, and no distortion of the field was observed. Hence the cylinder, when insulated from the rod, apparently had no effect.

It has been stated in some articles on short waves that aerial and counterpoise rods should be polished. Accordingly, a heavily insulated wire was substituted for one of the brass rods. There

was no noticeable decrease in radiation.

EFFECT OF ARTIFICIAL LIGHT

A 400-watt projection lamp was placed at the focus of a large reflector, and the beam of light turned on various parts of the transmitter. This was tried at different times in daylight and in the dark, but there was no detectable change in the radiation.

Once, when the light was playing on the aerial system, a rise of 5-10% was observed in the galvanometer reading. Upon turning out the light, the reading slowly went back to normal. W en the light was turned on, the needle took two or three minutes to rise; and when the light was turned off, the needle fell back during two or three minutes, the movement being very slow. It was suspected that this might be a heat effect, and upon examination it was found that the thermo-galvanometer (which was in a black case) was right in the path of the beam from the reflector; and was absorbing enough heat rays to cause a noticeable change in the galvanometer reading.

An arc, dissipating about 400 wats, was next tried, as it was thought that the ultra-violet light, which is emitted in larger quantities from an arc

than from an incandescent lamp, might cause sufficient ionization to affect the radiation. The result of this experiment was, however, negative, no effect being observed.

The antenna rods were blackened with a mixture of pulverized carbon and oil, and light was projected on them. No variation in radiation occurred with and without light on the rods.

EFFECT OF DAYLIGHT

Following an experimental method of West, a flashlight bulb was used for the wavemeter indicator instead of the galvanometer. The oscillator was set going in daylight, the wavemeter placed at such a distance from the transmitter that the bulb glowed very faintly, and the apparatus left until about an hour after dark. At that time the bulb showed as much light as ever. There had not been any particular drop in radiation with the going down of the sun. This was repeated several times, without any change being observed.

NEW TRANSMITTER BUILT

When illuminating the oscillator with the incandescent lamp, it was not possible to focus the beam on more than a small section of it at one time, because of its extended construction, necessitated

by the long straight rods. It was therefore decided to build a more compact transmitter.

The second transmitter employed two coils about 8 cm. in diameter, of $1\frac{1}{2}$ turns each, instead of the two rods previously used. The circuit was essnetially the same as before, except that the negative of the filament was connected to t e negative of the plate supply, (instead of ~~to~~ the positive) This transmitter, like the first one, oscillated freely over the whole condenser scale, the minimum wavelength obtainable (about 4.6 meters) being slightly lower than with Oscillator #1.

FURTHER EXPERIMENTS WITH LIGHT

Using the new transmitter, the effect of light was tried as before, but no difference could be detected between radiation in a beam of light and radiation in the dark.

The experiments up to this point had all been carried out in a building which is of steel construction, and in a room which is therefore practically surrounded by steel. Although no reason was apparent why the surrounding metal should cancel any light effect, such an effect itself is inexplicable, and therefore the apparatus was moved to another building. This building is of wood and

and well away from most of the other University buildings, so it answered the purpose admirably.

As a further improvement, a vernier device was put on the wavemeter condenser, to make sure that absolute resonance was actually being obtained. This is really necessary at 5 meters, because the resonance curve is very steep. The capacity effect of the human body affects the wavemeter quite considerably, so an extension system, by means of which the wavemeter could be accurately tuned with the observer several feet away, was also attached. For a description of these attachments see Figure 8.

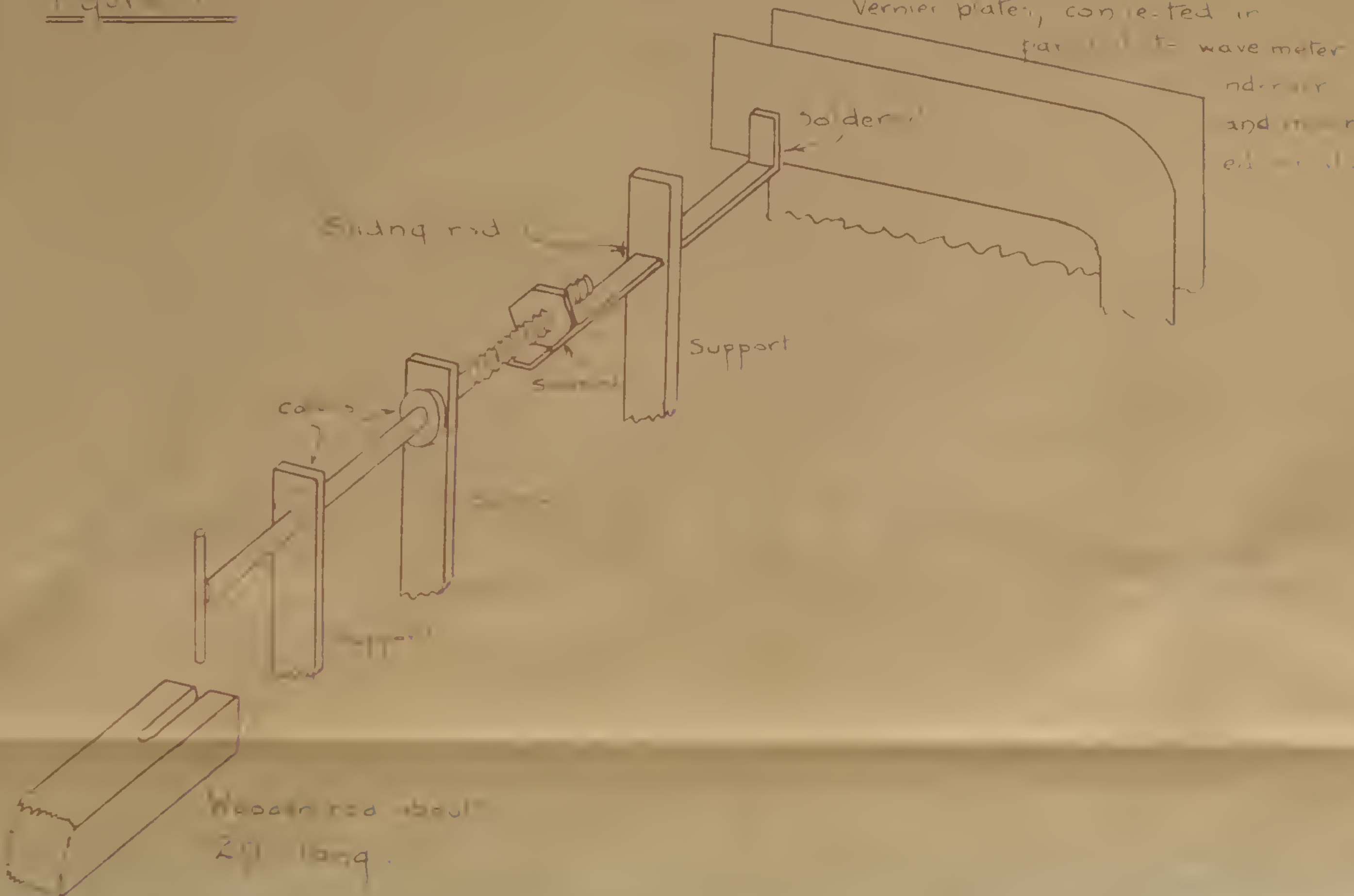
The oscillator was started up one afternoon at about two o'clock, and readings were taken for several hours. Table I shows the results obtained. It will be noticed that there was a gradual drop as the day wore on.

TABLE I

| Time | Plate current (milliamps.) | Fil. current (amps.) | Galvanometer reading. |
|---|---|---|---|
| 2:13 | 26.6 | 1.57 | 93 |
| 2:30 | 27.1 | | 90 |
| 3:00 | 27.1 | | 88 |
| 3:30 | 27.1 | | 85 |
| 4:00 | 27.2 | | 84 |
| 4:30 | 27.2 | | 84 |
| 5:05 | 27.2 | | 84 |

At 5.15, by which time it was quite dark, artificial light was projected on the oscillator,

Figure 9




WAVE-METER VERNIER DEVICE

and the galvanometer watched for any variation. No change was noticed until the 300-watt lamp (now being used instead of a 400-watt) was placed very near --- almost touching --- the plate and grid coils. The result of this was a gradual increase in wave-length of the oscillations as the coils heated up, but there was no increase in radiated energy, as nearly as could be determined. This increase in wave-length is probably due to expansion of the coils under the action of heat.

It was next decided to make an all-day run of the transmitter, from before sunrise till after sunset, as it was thought that this would bring out clearly any diurnal variation in radiation. Accordingly, such a run was made. Readings were taken at intervals of from ten minutes to about half an hour, from 6:30 A.M. to 6:30 P.M. A few representative readings are given in Table II, and a graph of the results is shown in Fig. 9.

TABLE II

| Time | Plate current (Milliamps.) | Fil. Current (amps.) | Plate Volts | Galvan. Reading. |
|---|---|---|---|---|
| 6:30 | 30.7 | 1.58 | 237 | 67 |
| 7:00 | 31.3 | | 236 | 64 |
| 8:00 | 31.3 | | 235 | $60\frac{1}{2}$ |
| 9:00 | 29.9 | | 234 | 55 |
| 10:00 | 30.7 | | 235 | 56 |
| 11:00 | 30.7 | | 235 | $54\frac{1}{2}$ |
| 12:10 | 30.5 | | 235 | 56 |
| 1:00 | 30.4 | | 235 | 57 |
| 4:00 | 29.6 | | 235 | $56\frac{1}{2}$ |

Figure 9

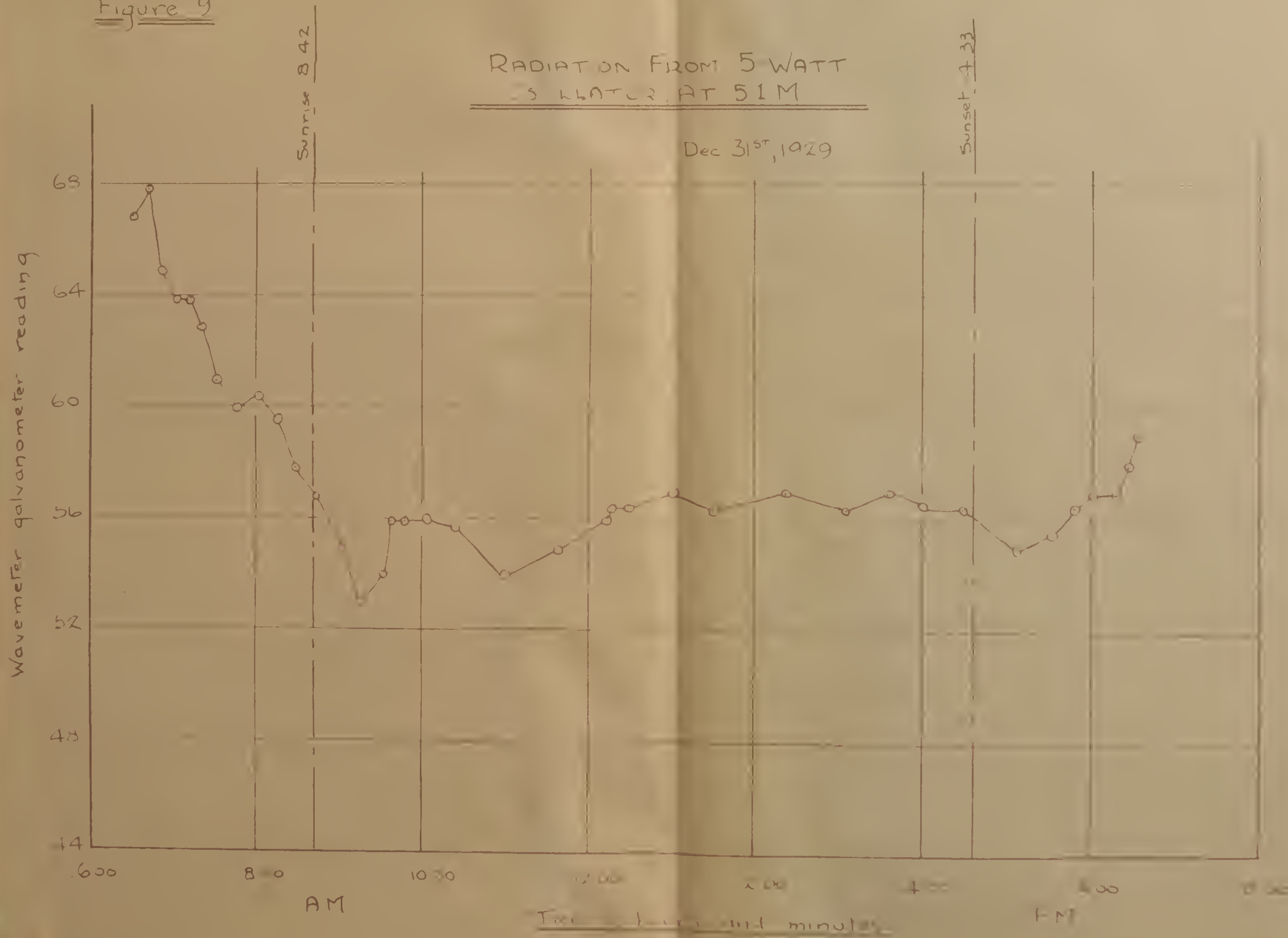

RADIATION FROM 5 WATT
AT 51 M
Dec 31st, 1929
Sunrise 8 42
Sunset 4 33
Wavemeter galvanometer reading
68
64
60
56
52
48
44
6 00
8 00
10 00
6 00
AM
PM
minutes

TABLE II (continued)

| Time | Plate current (milliamps.) | Fil.current (amps.) | Plate Volts | Galvan. Reading. |
|---|---|---|---|---|
| 6:00 | 29.6 | | 236 | 57 |
| 6:30 | 30.3 | | 236 | 59 |

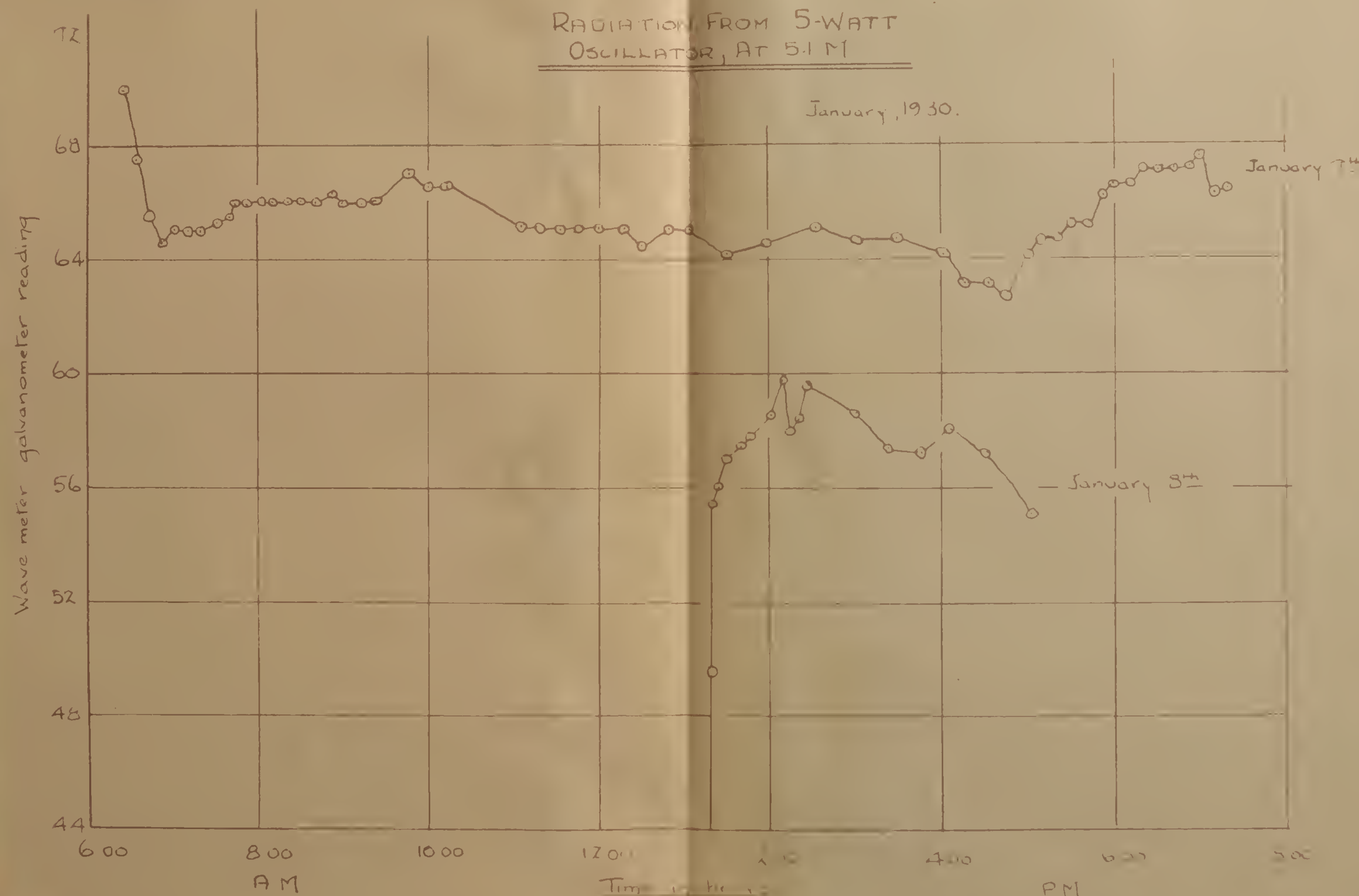
An examination of the graph shows a drop till a little while after sunrise, a fairly steady line during the day, and the beginning of a rise again after sunset. That is, instead of an increase in radiation with daylight, this graph would indicate the reverse to be true.

Another interesting observation is that at 6.30 A.M. and at 10:00 A.M. the plate readings were both 30.7, but the radiation was much different in the two cases. Also, comparing the readings at 10:00 A.M. and 6:00 P.M., the one with the larger radiation had a lower plate current, the wave-length being the same in the two cases.

An afternoon run was again made and continued until after 8:00 P.M., to determine if the radiation would increase with night-fall, as might be expected from Figure 9. No particular increase was, however, noted.

A further series of observations, over a whole day, were taken, this time from 6:20 A.M. till 7:20 P.M. Figure 10 shows the results of this run graphically.

Figure 10



RADIATION FROM 5-WATT OSCILLATOR, AT 5.1 M
January, 1930.
January 7th
January 8th
Wave meter galvanometer reading
72
68
64
60
56
52
48
44
6 00
8 00
10 00
12 00
4 00
A M
P M

On the same sheet will be noticed another curve for an afternoon run taken the following day.

Several more runs were made, but the results were not definite enough to warrant the formation of any conclusions either for or against diurnal variations.

VARIATION OF RADIATED ENERGY WITH INPUT VARIATIONS

It was then decided to examine the effect on radiated energy of changes in the input, to determine if such changes might be large enough to account for the fluctuations in output.

The filament current and plate voltage --- both from storage battery supply --- had been kept as constant as possible, the variation being determined by the accuracy with which the plate voltmeter and filament ammeter could be read. It was estimated that the potential could be read to within one volt, and the current to within 2/100 of an ampere. Using 235 volts on the plate, with a possible variation of plus or minus one volt; and with 1.60 amperes on the filament, plus or minus less than 2/100 ampere, the variation in voltage would be .85%, maximum, and in amperage 2.50%, maximum, or a total expected variation in input of 3.35%.

No data on the operation of the 205 D vacuum tube was on hand, but information available (7) regarding another tube (UX 210) employing an oxide-coated filament, showed that for this tube a variation of about 5% from rated filament voltage (corresponding to about the same variation from rated current) caused a variation in output of not more than 1%. The UX 210 was operating in this case at rated plate voltage. The 205 D was running at considerably under rated voltage (235 instead of 350). This fact should tend to make a variation of filament current for the tube used cause even a smaller variation in output than is quoted above for the UX 210, for the reasons given in the next paragraph.

If the plate voltage is sufficient to cause nearly all of the electrons emitted from the filament to go to the plate a slight increase in filament current, resulting in increased electron emission, should result in an increased plate current (hence greater radiation), due to nearly all the extra emitted electrons being attracted to the plate. If, however, the voltage is considerably below the saturation value, it is not nearly sufficient to attract

(7) QST, September, 1926. p.33.

all the emitted electrons; and an increased electron emission will therefore affect the plate current considerably less than in the first case discussed, because the plate voltage is not in a position to take full advantage of the extra electron emission.

However, we may make allowances for the differences in construction of the UX 210 and the 205 D, and assume that changes in filament current will affect our tube, not less, but more (say five times as much) than the 210 was affected in the case quoted. That is, assume that the radiation of the circuit using the 205 D is affected five times as much as the radiation of the circuit which used the UX 210. We then reach the conclusion that a $2\frac{1}{2}\%$ variation in filament current should not affect the output by more than $2\frac{1}{2}\%$.

In the case of plate voltage variations, the limit was only about 0.85%, and we should not expect this to affect the output by more than two or three percent, if as much as that.

From the above discussion, it will be seen that the fluctuations in output due to input variations were not expected to be more than 5%. Such variations would not account for the changes in radiation as actually found to occur, so to make quite sure that nothing was being overlooked, it

it was decided to measure experimentally the radiation changes with different input values.

A number of readings were taken and two graphs plotted, one of radiation against filament current (plate voltage constant), and the other of radiation against plate voltage (filament current constant). See Figures 11 and 12. The latter graph was about as expected, but the former was somewhat startling. A change of $1\frac{1}{4}\%$ in filament current (from the normal value) gives rise to a change in radiation of 13.6%. That is, our expected error in filament input was $2\frac{1}{2}\%$; and this would, on the basis of Figure 12, give us a difference in radiation of about 27%.

In the light of this information, no faith could be placed in the curves obtained of diurnal variation of radiation, and additional runs were therefore made using an improved technique.

IMPROVED METHOD OF KEEPING INPUT CONSTANT

It was first necessary to obtain a more accurate method of keeping the filament current constant.*
This was accomplished by,-

(1) pasting a duplicate scale on the glass above the ammeter scale, to avoid parallax,

(2) reading the meter with a magnifying glass, fixed above the meter, and

*No other similar tubes were available at this time, or a substitution would have been made to determine if the abnormal output variations were caused by the particular tube used, or if they were due to the high frequency employed.

Figure 11

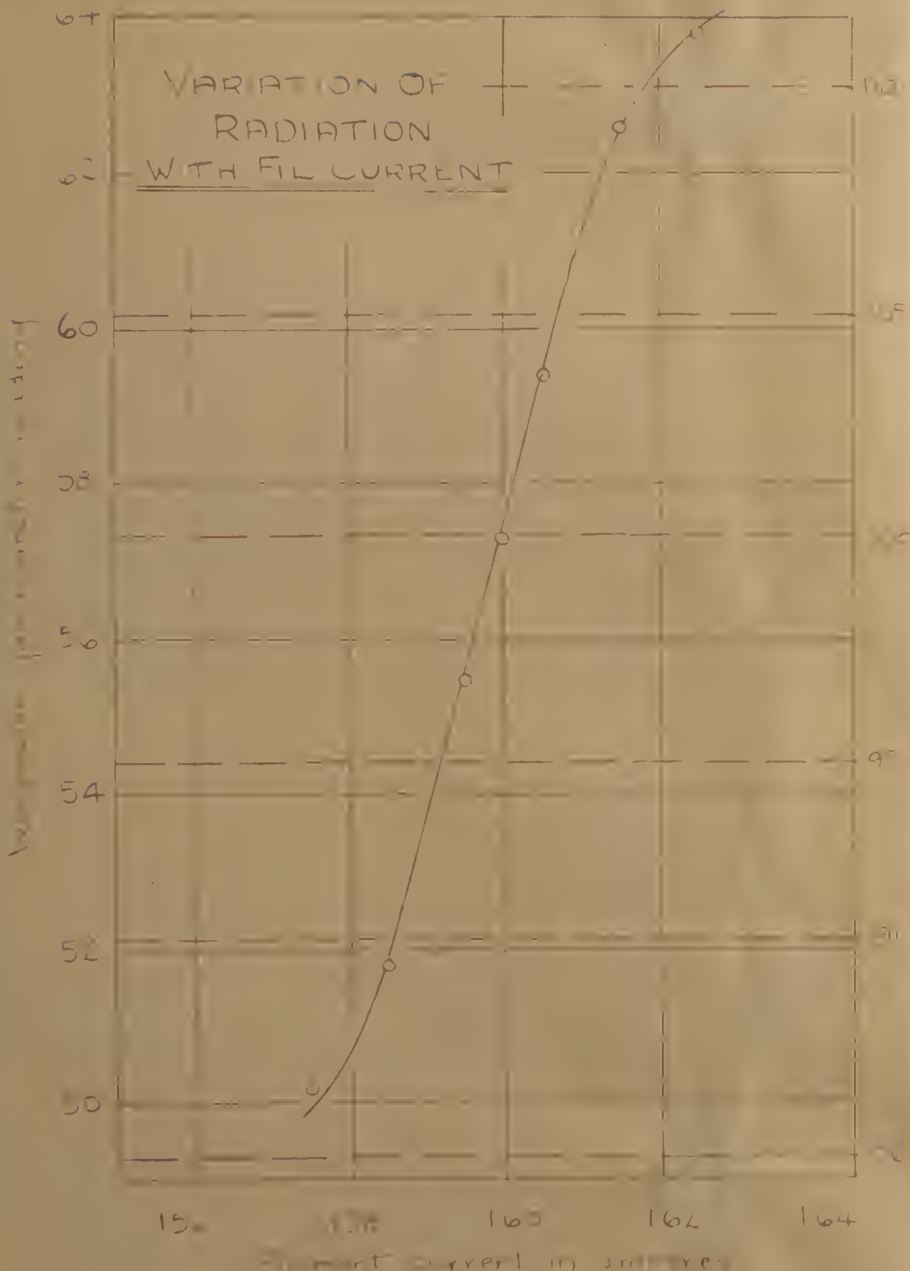



Figure 12

(3) using a rheostat of two resistances in parallel, one resistance being about five ohms, and the other about 100 ohms.

To take a reading, the observer moved his head to and fro until his right eye was in such a position that the two scales appeared to coincide; and then he brought the needle to the line on the scale indicating 1.60 amps. (which was the current used, being the normal value for the tube). A rough adjustment was obtained with the low resistance, and a fine adjustment with the high resistance.

By this method, it was estimated that the current could be kept constant with an error not greater than 0.001 ampere. This corresponds to a variation in output of 1.4% (see Fig. 11). By exercising more care in reading the plate voltmeter, variation due to this cause could be kept within one volt (corresponding to an output change of about 2%), so that the total variation in radiation due to input changes could now be kept within about 3½%.

It is felt that previous investigators in this field have probably not paid sufficient attention to the fluctuations mentioned above and for which corrections were subsequently made; so that some of the effects which have been noticed were in all

probability really due to this cause.

CHECKS ON DIURNAL VARIATION OF RADIATION

With possible errors now inside reasonable limits, another afternoon run was made. Figure 13 shows the result of this run, and indicates that there was a slight drop near sunset, though the estimated possible error would about cover this variation.

Accordingly, to see if there were really a drop dur to the rising of the sun, as was indicated by the first all-day run (Fig. 9), the oscillator was started just after midnight and allowed to run until ten o'clock in the morning. The graph of this is given in Fig. 15, and shows that the radiation was practically constant for the whole period.

To make a final check on any sunset effect, a run was made just before noon. A graph of this run is on Fig. 14.

E
AFFECT OF TEMPERATURE CHANGES

It will be noticed (Fig. 14) that the radiation steadily increased over a period of three hours. This increase was observed while the run was in progress, and an explanation was sought. It had been noticed that the temperature near the oscillator was going up slowly, and in the period,

Figs 13 & 14

RADIATION FROM 5-WATT OSCILLATOR AT [illegible] METERS

Figure 13

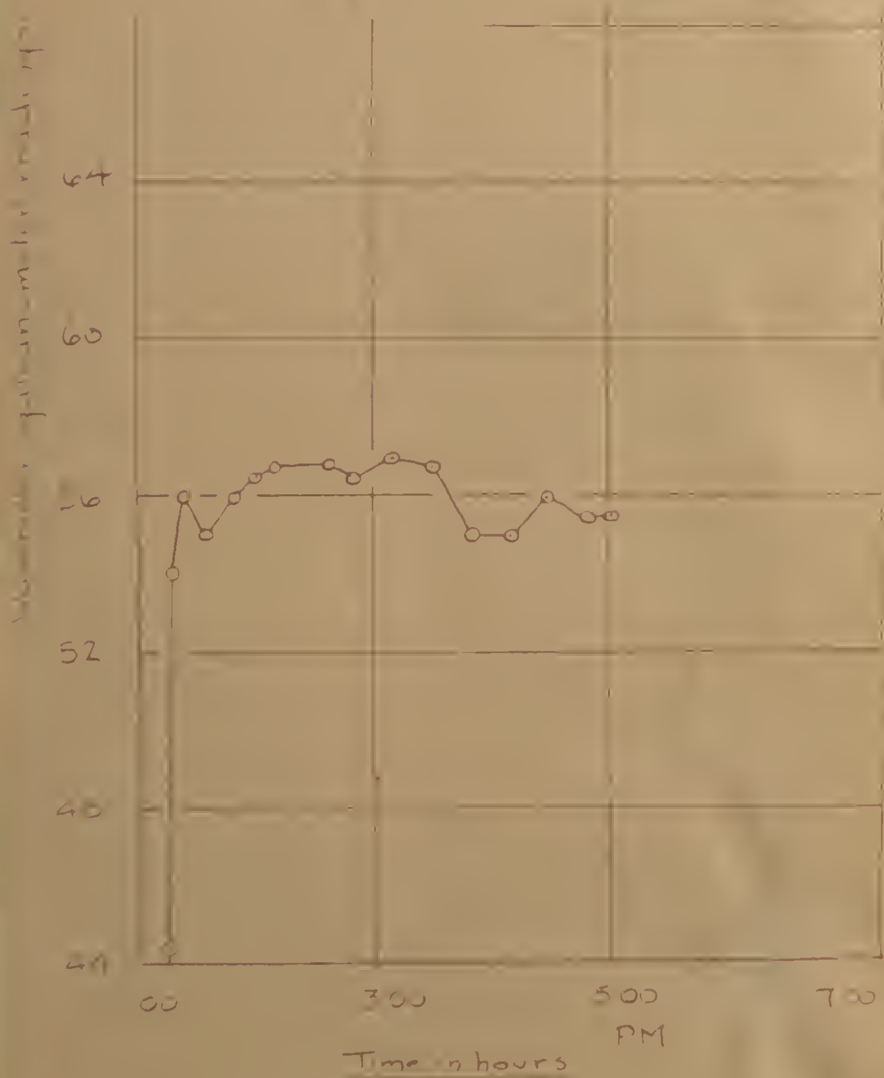
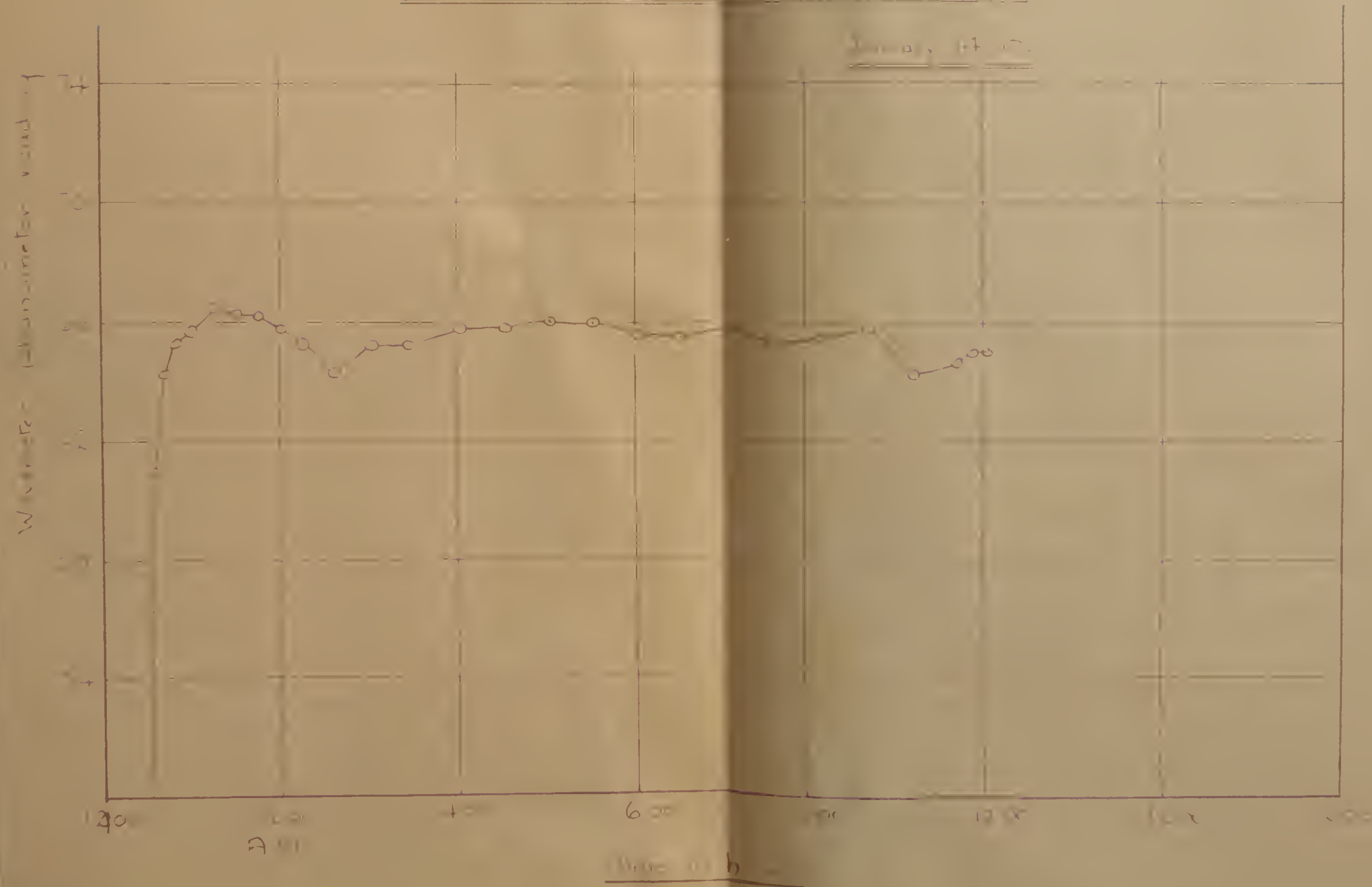



Figure 14

Figure 12

RADIATION FROM 5 WATT OSCILLATOR
AT 51 METERS



twelve o'clock to three o'clock, the increase was some ten degrees centigrade. The idea suggested itself that temperature might be the disturbing factor, and to test it out the door was opened. The room temperature rapidly dropped, and as it did so, the radiation dropped likewise. A drop of 20° C. caused a decrease in radiation of from 64 to 44, wave-meter galvanometer readings, or a drop of 31%.

It might be mentioned here that rising temperature had been checked against radiation once before, but this was done prior to the improved technique, and no connection between the two had been observed. The reason must be of course that such effect was obscured by the fluctuations due to variations in input.

It was thought that the observed variation in output due to temperature changes might be accounted for by one of two things: the thermo-galvanometer might possibly be affected by the temperature drop, and might be indicating a radiation drop where none existed; or, in view of the great sensitivity of the output to slight changes in filament current (and therefore filament temperature), a change in the temperature surrounding the vacuum tube might be

affecting the output to the extent observed in the experiment.

To check the first possibility, the oscillator was set going, and the reading of the galvanometer noted. The case of the galvanometer was insulated from temperature changes by packing it around with cotton batting, and the temperature of the room was varied some $20^{\circ}$ C. The galvanometer reading was found to fluctuate as it had done before.

Keeping the temperature of the room constant, the 300-watt lamp was placed against the galvanometer and the outside of the cotton now surrounding the case heated $25^{\circ}$C. or so above the temperature of the room. Practically no increase in the reading took place. This demonstrated that the indicating instrument was not responsible for the observed fluctuations.

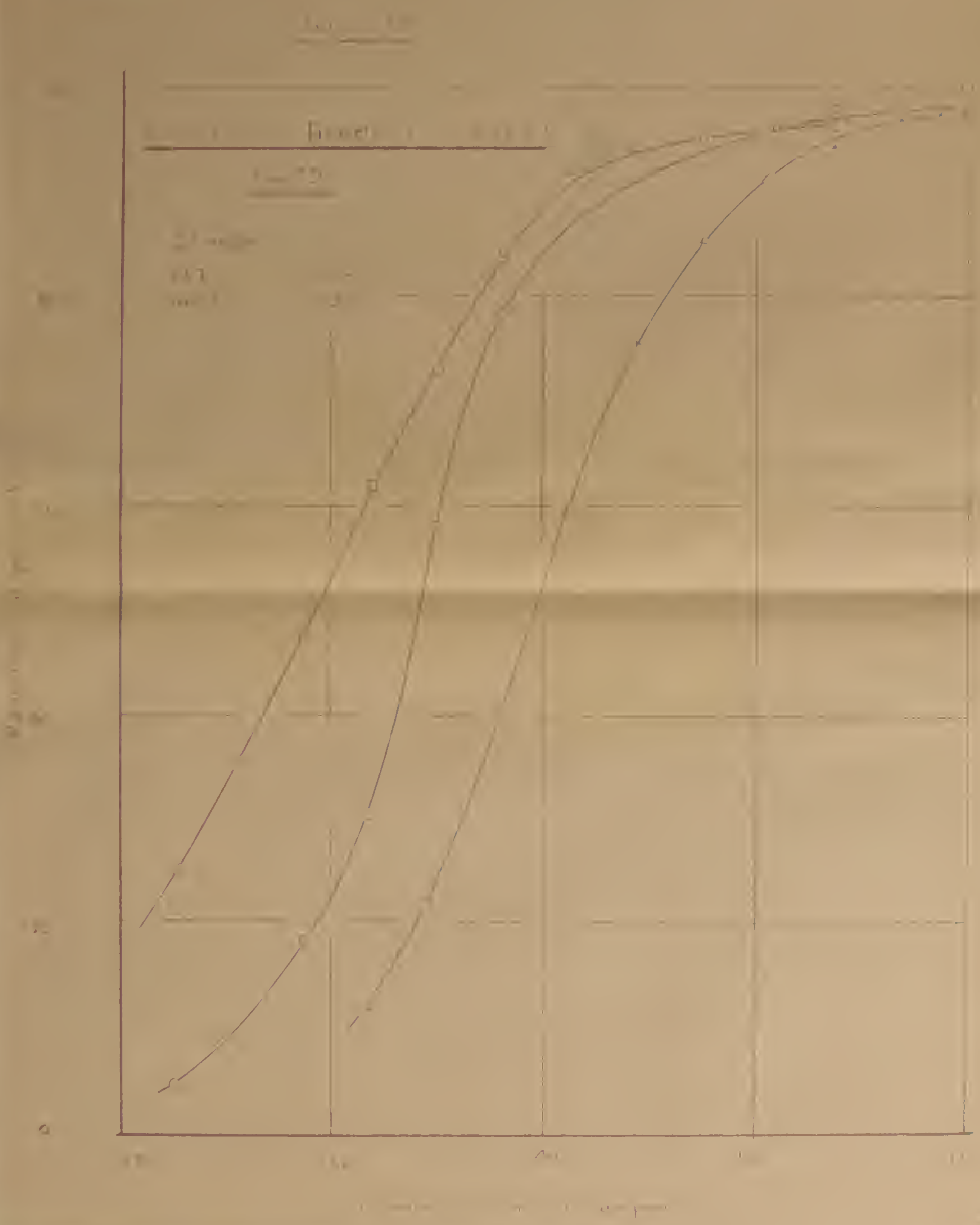
To determine if the temperature surrounding the vacuum tube were the important factor, the 300-watt lamp was placed near the tube. The galvanometer reading began almost immediatly to increase, going up steadily as the surrounding air heated up. Upon removing the lamp, the reading dropped again. This was tried several times, with identical results.

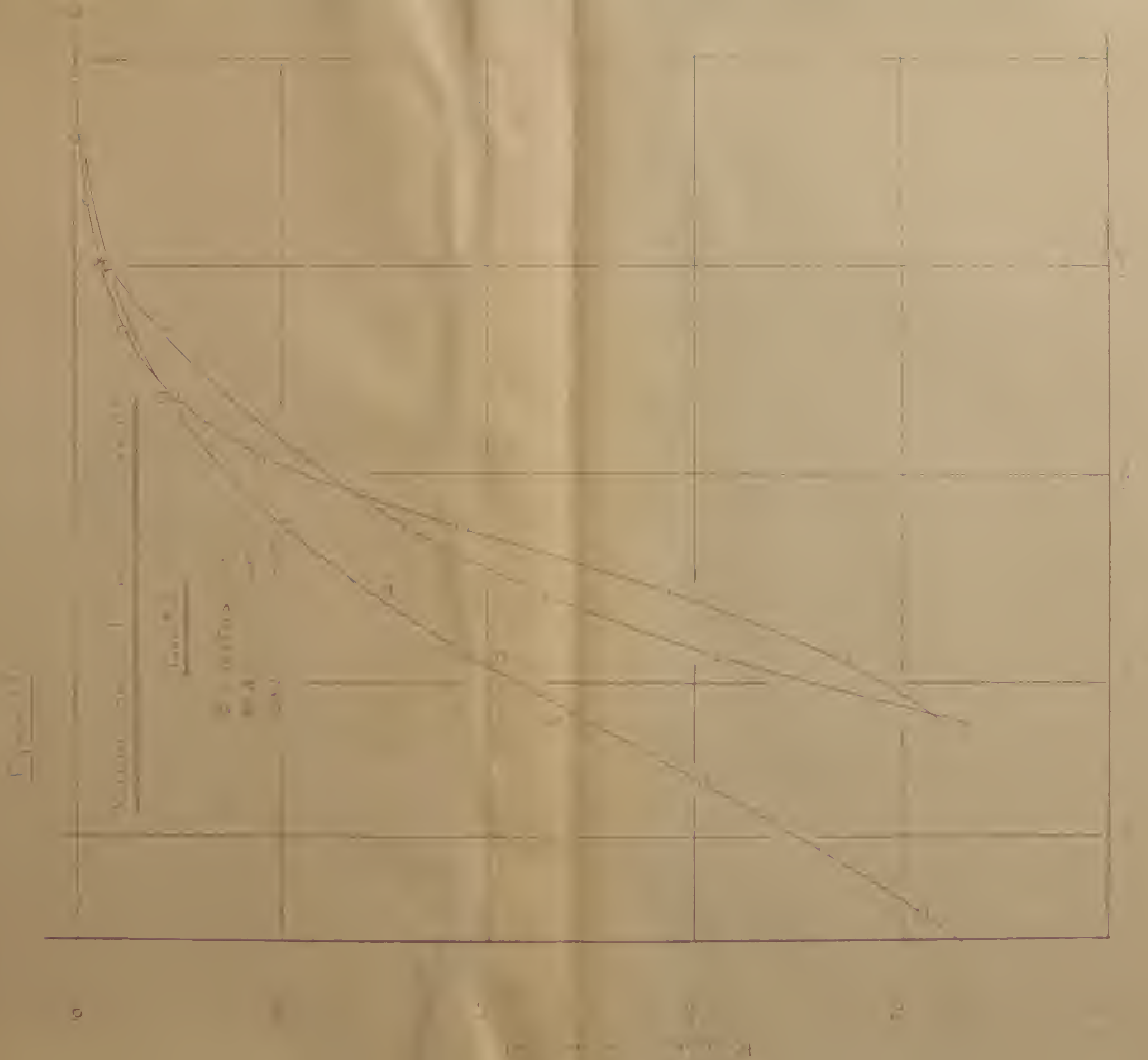
It thus seems apparent that all variations in output noticed in the course of these experiments may be ascribed to one factor, namely, the abnormal sensitivity of the vacuum tube to small changes in filament temperature. These changes in filament temperature were caused by, first, small fluctuations in filament current, and second, changes in room temperature.

## FURTHER STUDY OF SENSITIVITY OF OSCILLATOR TO INPUT VARIATIONS

It was then decided to investigate further the peculiar way in which the radiation responded to such small changes in filament current, to ascertain if such were due to the very high frequency of the oscillations or merely to some peculiarity of the vacuum tube employed.

Accordingly, an oscillator was constructed, using the familiar Hartley circuit (see Fig. 21), which oscillated from about 75 meters to 200 meters. Curves were then plotted of radiation against filament current for two wave-lengths, one about 80 meters and the other about 190 meters. Two other 205 D tubes were procured,and similar curves for these plotted at 5, 80 and 190 meters. These six curves are shown on Figures 16,17 and 18. The





vacuum tube which had been used throughout the experiments, and which has had the greatest number of hours service is called Tube #1. Tube #2 has not had quite as much wear as #1, and Tube #3 is new.

Referring to the graphs, the following points may be noted:

1. Each curve has a steep portion, which for the older tubes is at a higher value of filament current. Remembering that these filaments are oxide-coated, this simply means that as a tube ages, a higher filament temperature is required for a given electron emission. Therefore, if an experimenter requires his output to be independent of small filament changes, it is not sufficient to work at rated current, unless he is sure that this value of current is on the flat part of the Radiation --- Filament temperature curve. With a new tube rated filament current is good enough, but with an old tube, it is not.

2. The shape and position of these curves are not independent of frequency. The 190 meter curves are flatter, and in general give a greater radiation for a given filament current. The 80 meter curves have a part of their length where they are steeper than the others. This fact is brought out by the

curves of Figure 19, which are the slopes of the Radiation-filament-temperature curves plotted against temperature. The 5 meter curves have a tendency to be concave downward over their whole course, while the other curves have each a point of inflexion.

These facts are interesting, though of no particular practical importance if the tubes are operated on the flat part of the curves, since here the different wave-lengths give coincident curves.

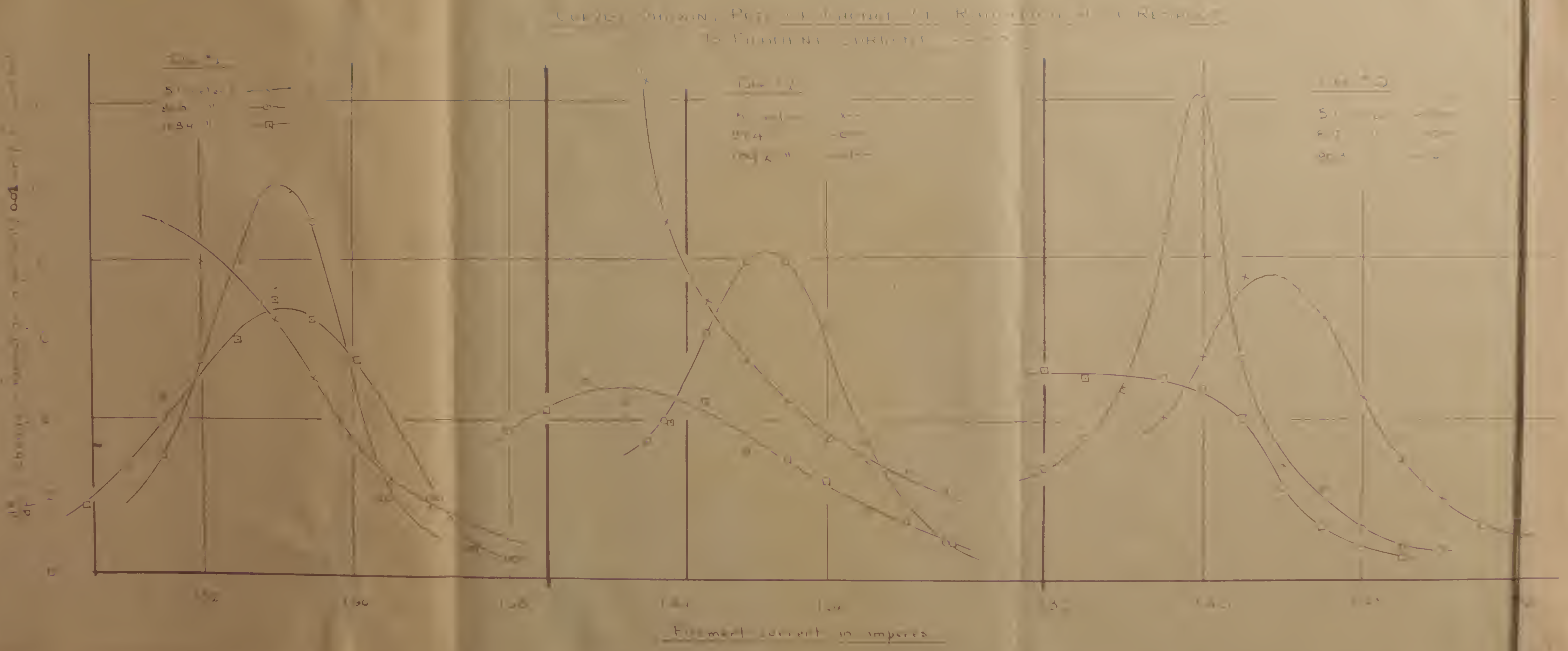
FREQUENCY VARIATIONS WITH FILAMENT CURRENT CHANGES

The subject of the frequency of a triode oscillator and its dependence on filament current and plate voltage has recently been thoroughly studied by several investigators (8). It has been shown that for some values of plate voltage, grid voltage and filament current, small changes in these quantities lead to large frequency variations. For other values, the variations are negligible.

Upon varying the plate voltage of our five-meter oscillator from 218 to 253, a very slight increase in wave-length was noted at the higher voltages. Over the entire range of filament current, however, no detectable wave-length change was found. Hence, for the oscillator as used in this research,

(8) See D.F. Martyn, Phil. Mag., V.4, P.922 Nov. 27., who has satisfactorily explained these variations.

Figure 19



the frequency changes due to filament and plate input variations were negligible. This means that the transmitter was operating on the flat parts of D.F. Martyn's frequency variation curves.

SUMMARY OF RESULTS

1. Contrary to C.H. West's results, light has been found to have no perceptible effect on 5-meter radio waves. His results may be explained in two ways:

a. The importance of input variations was possibly not fully recognized, and he was unwittingly working on the steep part of the Radiation-filament-current curve.

b. The temperature of the environment varied considerably, and the result was the same as if the input had fluctuated in value. West's transmitter was probably exposed to sunlight, so that in the middle of the day the temperature and radiation were at a maximum, while towards evening they dropped off to a minimum. This seems likely, since West found that in using artificial light he had to have a parabolic reflector almost enclosing the oscillator; that is, he had to heat up the vacuum tube to get his supposed "light effects".

2. It has been found that the variation of radiated energy with filament current fluctuations may be very considerable, even when working at the rated value of filament current.

It is thus shown that it is important in certain cases to make sure that the tube is operating on the flat part of the Radiation-filament-current curve.

3. In using the Lecher-wire system for measuring wave-lengths, erroneous results are obtained when a glow-lamp is used to pick out voltage nodes and loops.[9]

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(9) In connection with the peculiar form of voltage wave noticed in some cases (see Figures 4,5,5a.) an article has just appeared (E. Takagishi, Proc. Inst. Rad. Eng. V. 18, p. 513, 1930) calling attention to double humped waves which were found to occur on Lecher wires under certain conditions. The wave-form mentioned is not quite the same as those encountered in this research and the reasons for their occurrence do not appear to be identical; but it is mentioned here as a further crop up in making Lecher-wire measurements. example of peculiarities that sometimes

## PART B: The Generation of Waves Shorter than Five Meters.

### INTRODUCTION

The production of continuous electromagnetic waves, of length about the order of one meter or less, is of importance for two reasons; in the first place, a study of the properties of these very short radio waves is of considerable interest in itself; and secondly, by their aid, it is possible to investigate certain theories as to the constitution of matter; for example, the Debye dipole theory has been, and is now being investigated by this method.

These very short waves have been produced by several groups of investigators, located in Germany, Japan and England.(10) Their results were, however, obtained with tubes whose construction is somewhat different from those commonly used on this continent; and it was thought worth while to investigate the possibilities of the low-power vacuum tubes which are available here, to try out different circuits, and determine what might be done with them in producing these ultra-short waves.

(10) H.E. Hollman, Proc. Inst. Rad. Eng., V. 17, p.229, 1929, gives a very complete bibliography.

The chief difference between the foreign and our own tubes is that the former have the plate, and very often the grid leads brought out through horns in the side of the glass. The latter, on the other hand, have the plate and grid leads running side by side to the base. The result is that the leads in our own tubes are longer, and the plate-to-grid capacity is considerably higher. Hence, these tubes, on account of their higher internal inductance and capacity, are not as well suited for short-wave production as those of foreign make. But in any case, it was decided to see what could be done with them.

## EXPERIMENTAL

### Circuit of Gill and Morrell

As a starting point the circuit used in oscillator #1 (See part A) was employed. The plate and grid rods were successively shortened, until the set refused to oscillate further. It was found that different-sized choke coils had to be used to maintain the strongest oscillations at any particular wave-length, Table I giving the values which have been used as most efficient.

TABLE I

| Wave-length in meters. | Diameter of coil | Size of wire used | No. of turns. |
|---|---|---|---|
| 5-3.0 | 2.5 cm. | #26 | 20 |
| 2.0-3.0 | 1.5 cm. | #26 | 20 |
| 1.6-3.0 | 1.5 cm. | #34 | 22 |

The limit of this circuit seemed to be about 2,0 meters. Below that point the oscillations were very feeble, and were not detectable at 1.9 meters. At this stage the length of the rods was about 8cms.

Several 205 D vacuum tubes were tried in the above circuit but there was not much difference in their behaviour.

A U V 202 was next used, and was found to go down to about 1.7 meters, below which point it would not oscillate stably.

CIRCUIT EMPLOYING ELECTROSTATIC COUPLING

The circuit (11) shown in Figure 22 was next tried. This circuit was designed to utilize electrostatic coupling in the tube between the plate and grid; but it is to be noted that with our tubes some magnetic coupling between the plate and grid leads is unavoidable, as they parallel each other through the tube base.

(11) Hidetsugu Yagi, Proc. Inst. Rad. Eng., V. 16, p.715, 1928.

Figure 21

Hartley circuit

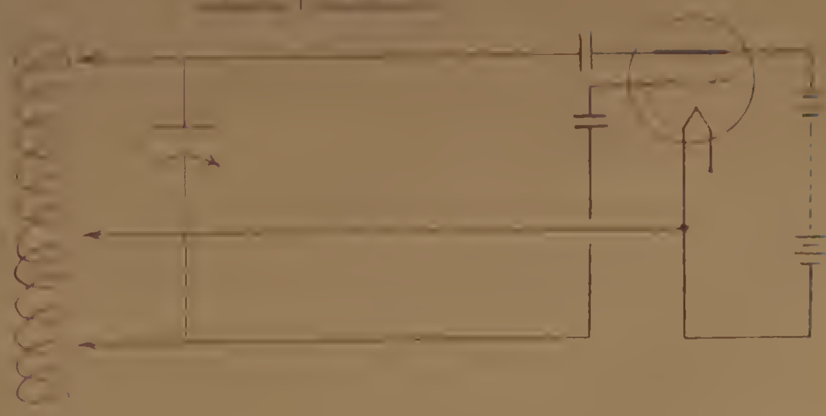
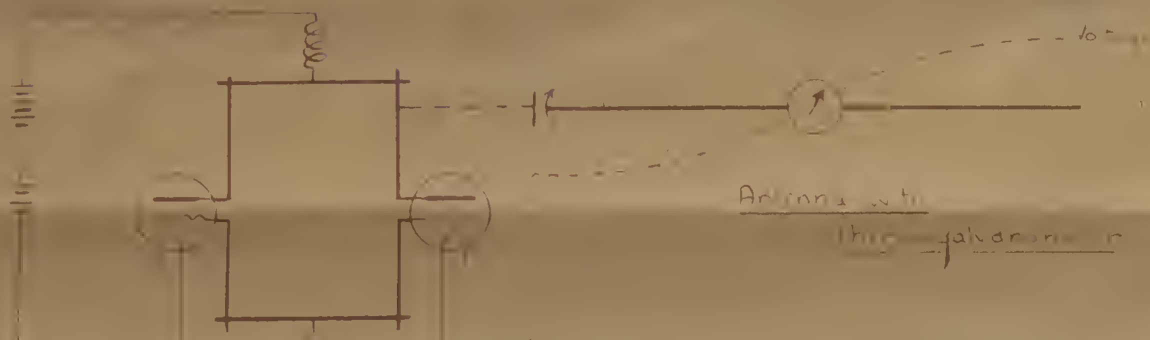
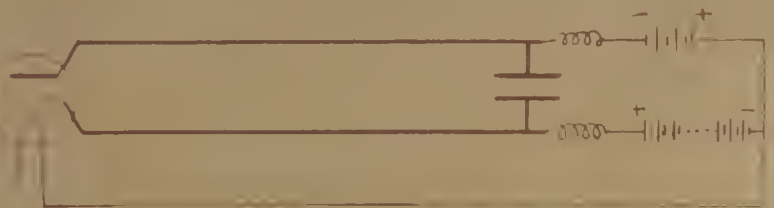


Figure 22




"Electrostatic Coupling Circuit

Figure 23



Continuous Wave circuit

This circuit gave much stronger oscillations than the previous one; and it was possible to go down to about 1.6 meters with it.

CIRCUIT OF BARKHAUSEN AND KURZ

The circuit (see Fig. 23) of Barkhausen and Kurz (12) has been used for the production of waves as short as 24 cm., so an attempt was made to obtain oscillations by this method.

It will be observed that this circuit has a high positive potential on the grid, and a negative potential on the plate, instead of the usual arrangement. The oscillations take place between the plate and the grid, and are independent of the external circuit. Schebe (13) found, however, that by coupling to the tube a circuit consisting of two parallel wires, shunted by a bridge and connected to plate and grid, respectively, a considerable increase in the strength of the oscillations occurred. For certain positions of the bridge the radio-frequency current was a maximum. It was also found that, whereas the plate milliammeter in general showed no deflection, when maximum oscillation current occurred the plate current rose

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(12) Barkhausen & Kurz, Zeits. f. Physik, V.21, p.1., 1920
Radio News, April, 1928, p.1143.
Also see note (10)

(13) Scheibe, Ann. d. Phys., V.73, 54, 1924.

to quite a pronounced value. The plate current may then be used as a measure of the strength of the "Barkhausen - Kurz" oscillations, as these have been named.

Using this circuit, therefore the bridge was moved along the wires, and the plate milliammeter watched for any deflection. At one point a slight movement of the needle was observed, the grid voltage being about 90 and the plate voltage zero. This indicated that weak oscillations were occurring , but attempts to strengthen them by readjusting the bridge failed. Other plate and grid voltages were tried, but no better results were obtained, so it was decided to leave this circuit and try to develop the electrostatic coupling method further.

PRODUCTION OF HARMONICS

Since the limit of the electrostatic coupling method appeared to be about 1.6 meters, it was decided to attempt to increase the harmonics generated, to see if they could be made strong enough to be utilizable.

As increased plate voltage is usually successful in bringing out the harmonics, this method was tried, with a large grid bias being employed to keep down the plate current.

For reception of these short waves, as well as for their measurement on Lecher Wires (see page 44) it is desirable to have the radio frequency output modulated to an audio-frequency note.

It, therefore, seemed possible that both these functions (first, production of harmonics; second, modulation of output) might be performed by using an alternating potential on the plate, either alone or in series with the normal D.C. value. The second method has most to commend it, and therefore the normal value of 360 volts D.C. was used, with 100 volts, 200 cycles, in series with it.

To measure the harmonics, an antenna made up of telescoping brass rods with a thermo-galvanometer in the middle, was constructed and connected to the oscillating circuit in the manner shown in Figure 21. This type of antenna should pick up most energy from the main circuit when it is half a wave-length long. The voltage distribution is then as shown in the diagram. It was thought that as the length of the antenna was successively lengthened or shortened a series of maxima would occur in the galvanometer readings, as the antenna-length became a half-wave for each of the harmonics.

Upon taking a number of readings, however, it was found that maximum current occurred when the antenna was about 53 cm. long (see Fig. 24). The current dropped off gradually as the antenna was shortened or lengthened from this value and no other maxima at all were detectable. From this result we might be led to believe that the fundamental wave-length was 2x53 = 106 cms (assuming our half-wave antenna to be working properly as such), and that the harmonics were all so weak as to be negligible, However, the wave-length had just previously been measured on the Lecher-wires as 183 cms., so something seemed wrong. It might be well here to mention how, in this case, the Lecher wire measurements had been made.

LECHER-WIRE MEASUREMENTS

The shortest wave-lengths obtained in this research had not been measured directly but had been approximated by extrapolation on an improvised wave-meter. At the lowest wave-length reached, however, it was desirable to obtain an absolute measurement of the wave.

It was not possible to use the thermo-galvanometer method with the Lecher-wires as insufficeint radio-frequency energy was produced to give a good galvanometer reading. Hence a vacuum tube detector, with a telephone head-set in the plate circuit

(See Fig. 25), was used as an indicator. This explains one of the reasons why a modulated radio-frequency current was desired, as mentioned on page (42).

Using the condenser at the generator end of the Lecher wires, the system was tuned to give a maximum noise in the phones. A shorting bridge was used, as in the previous measurements, to indicate points of minimum voltage, at which points the noise in the phones was a maximum. The nodes were not well defined, however, and although two half-waves were picked out, one 92 cms. and the other 91 cms. long, it was felt that the resultant wave-length (183 cms.) might possibly be in error.

WAVE LENGTH BY LINEAR OSCILLATION

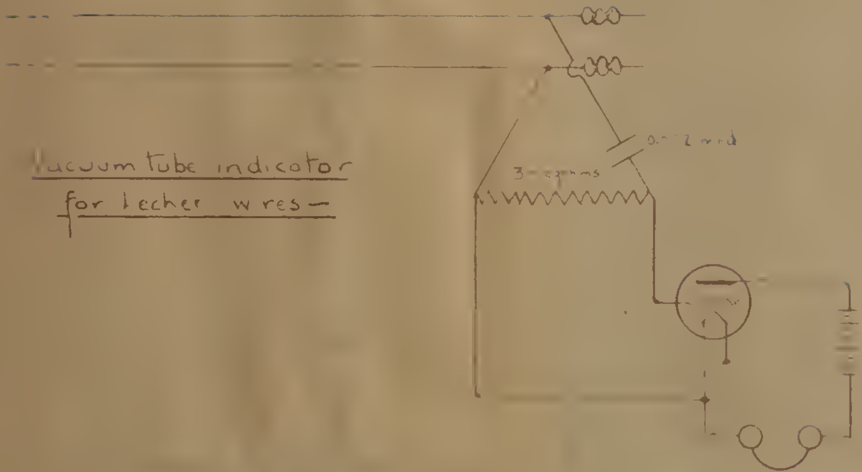
Method

Since the Lecher-wires gave the wave-length as 183 cms., and the half-wave antenna indicated it to be in the neighborhood of 2x53 = 106 cms., it was decided to investigate the wave-length and the proportion of harmonics present by another method.

It has been shown (14) that for the free electrical oscillation of a straight metallic rod, the ratio of wave-length at resonance to length of rod is about 2.12. By obtaining resonance in a rod,

(14) C.R. Englund, Bell Tech. Jour., V.7. p.404, 1928

Vacuum tube indicator for Lecher wires—



therefore, it is possible to measure wave-lengths with an accuracy dependent upon the sharpness of the resonance curve.

For the linear oscillator the telescoping antenna, with the galvanometer in the center was used; and a straight piece of wire, 53 cm. long, was connected to the transmitter for the radiating system.

The oscillator was started, the telescoping rod placed about 30 cm. from the antenna, and a resonance curve for the rod was plotted (see Fig. 24). The peak of the curve corresponded to the rod length of 76½ cms., which represents a wave-length of 1.61 meters. The harmonics were searched for by continuously shortening the rod, but for lengths corresponding to half a wave-length for the various harmonics, no trace of maxima occurred in the galvanometer readings.

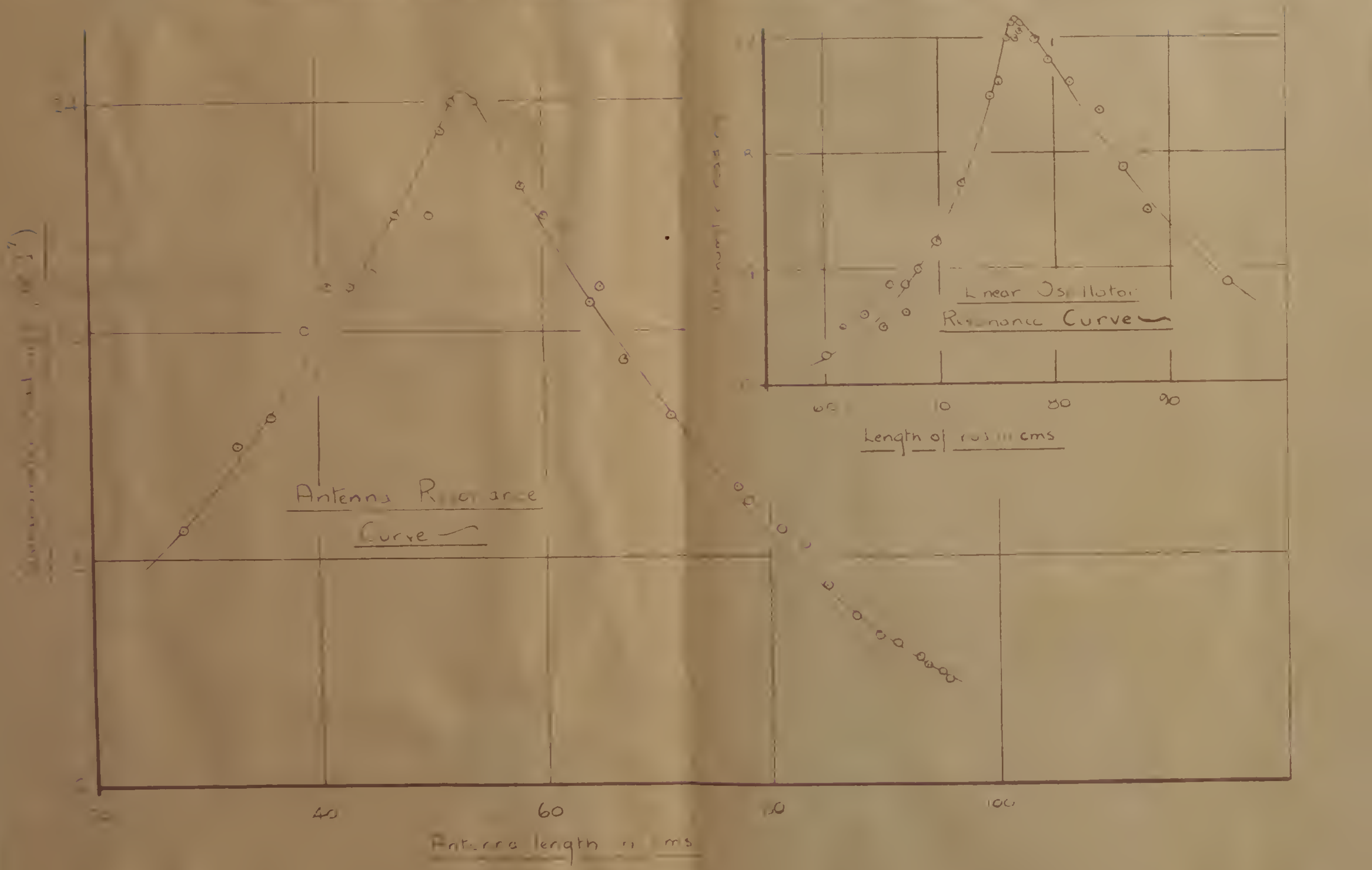
It was therefore concluded that the fundamental wave-length was 1.61 meters, and that the harmonics were all quite weak.

EFFECT OF A.C. ON PLATE

Upon the application of an alternating potential to the plate, in series with a direct potential, a considerable increase in the antenna current had been

Figure 14

## RESONANCE CURVES FOR ANTENNA AND LINEAR ROD



observed. It was thought that this might be due merely to the increased voltage, which would occur for the peaks, though the average voltage would be the D.C. value. If increased voltage were the determining factor, therefore, a direct voltage equal to the peak value of the A.C. plus D.C. should result in even greater radiation than the combination voltage, since the higher voltage is then continuously sustained instead of being reached only momentarily two hundred times a second.

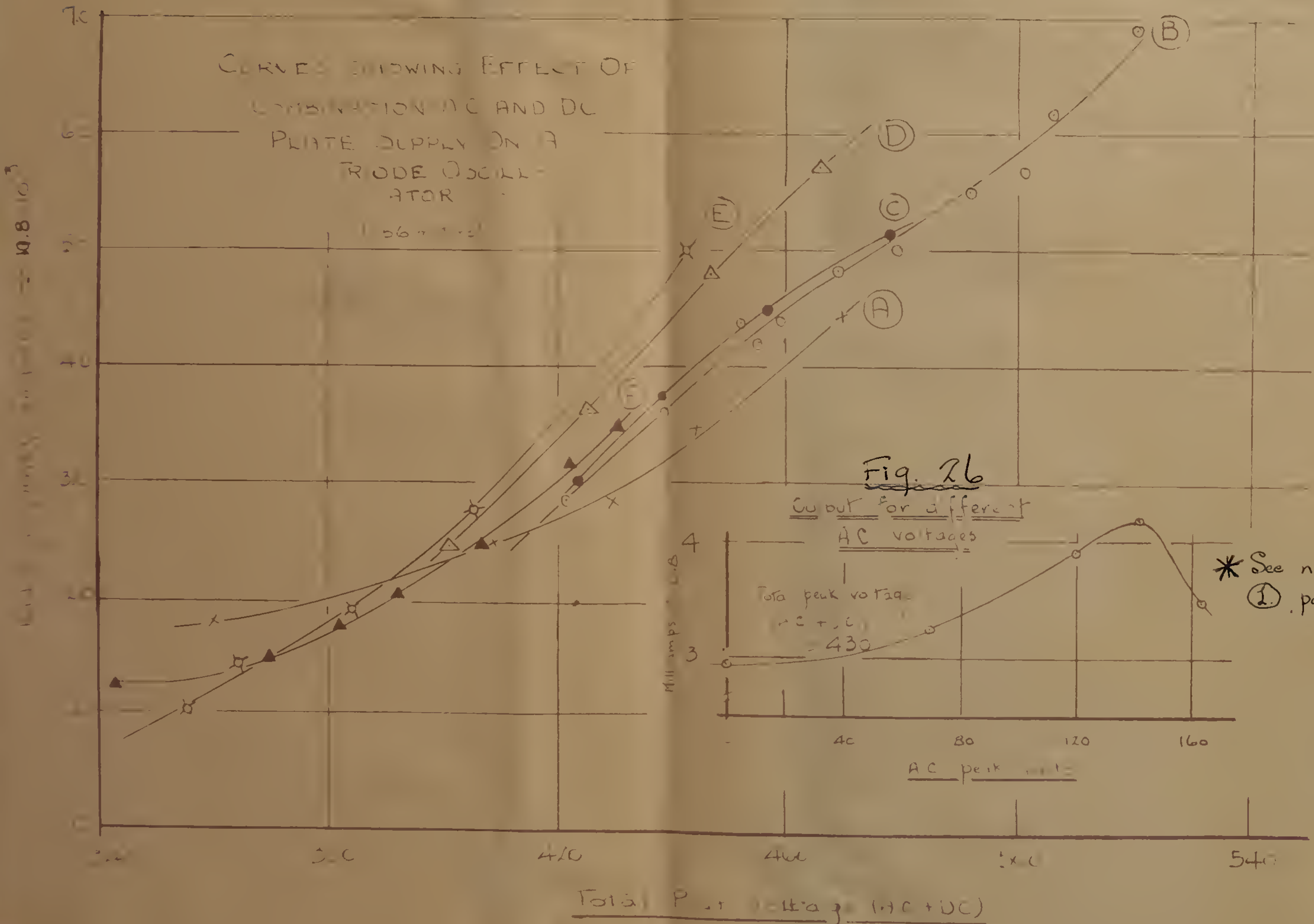
Accordingly a direct voltage was applied to the plate equal to the peak voltage previously used. The resulting antenna current was not as great as before, instead of being greater.

Following this a number of readings were taken of antenna current corresponding to different combinations of A.C. and D.C. plate supply. Curves were plotted, which are shown on Figure 20. The curves represent the following plate combinations,--

Curve A: Peak voltage, pure D.C.
" B: 360 volts constant D.C., plus different peak values of A.C.
" C: 332 volts D.C., plus variable A.C.
" D: 310 volts D.C., plus variable A.C.
" E: 289 volts D.C., plus variable A.C.
" F: 267 volts D.C., plus variable A.C.

An additional curve has been plotted, showing the effect of different proportions of alternating

Figure 20




* See note (1). page 49

voltage, on the antenna current, the total peak voltage being kept constant at 430.

These graphs indicate that a combination of A.C. and D.C. plate supply produces considerably stronger oscillations than does pure D.C. on the plate. It also appears that the proportion of A.C. to D.C. is of importance, there being a certain value of A.C. for a given peak voltage which will give best results.*

To bring out the effect of combination plate supply in a slightly different way, the dimensions of the oscillator were reduced till with pure D.C. on the plate the circuit would not oscillate at all. Upon using a combination, however, strong oscillations again occurred.

It was observed, too, that even when oscillations could be produced with D.C. alone, they were not as stable as with D.C. plus A.C. That is, any disturbing influence in the proximity of the oscillator, such as a wave-meter or the human hand, would cause the plate milliammeter to go up as much as 10 milliamperes, and sometimes cause oscillations to cease entirely. With D.C. plus A.C., however, such influences affected the meter by only a milliampere or so, and the oscillations were not easily damped out.

* See note (1), page 49.

## SUMMARY OF RESULTS

1. Several short wave circuits have been investigated, using two types of vacuum tubes, the 205 D and the UV 202. It appears as though the "electrostatic coupling" circuit will give best results with these tubes. The lowest wave-length attained with pure D.C. supply was about 1.61 meters.

2. The discovery has been made that a combination of A.C. and D.C. on the plate of the vacuum tube is much more effective in producing very short waves than is pure D.C. The oscillations produced are stronger and more stable, and it is possible to go to lower limits with this combination than with the ordinary method.

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NOTE 1

Further work which was carried out after the completion of this thesis showed that curve F., Fig. 20, Plate XII was in error, as it should lie above and not below curve E. Therefore, with the ranges of A.C. and D. C. so far employed, we are not yet justified in assuming that the curve of output against different proportions of A.C. has a maximum point, as would be indicated by Fig. 26, Plate XII.

NOTE 2

Experiments which have just been performed with 60 cycle as well as 200 cycle A.C. seem to show that frequency may be of some importance in using combinations of A.C. and D.C. plate supply, as the 200 cycle curves indicate a slightly greater output than the 60 cycle ones.

However, these and other matters are now being investigated by the writer, and will be cleared up in due course.